AC 2010-2353: FIRST-YEAR AND CAPSTONE DESIGN PROJECTS: IS THE BOOKEND CURRICULUM APPROACH EFFECTIVE FOR SKILL GAIN?

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First-Year and Capstone Design Projects: Is the Bookend Curriculum Approach Effective for Skill Gain?

Abstract

Universities and colleges across the country are being challenged to graduate undergraduate engineering students who are technically and professionally proficient. Project-based curriculum reforms have been instituted within several engineering programs in an effort to address this demand. The pedagogical philosophy implemented by several institutions positions project-based courses at the beginning and end of the undergraduate engineering curriculum—creating a bookend curriculum with First-Year Engineering Projects courses and Senior Capstone Design courses. First-Year Engineering Projects courses provide students with hands-on engineering opportunities and introduce students to professional components of an engineering career. Senior Capstone courses also incorporate technical knowledge and real-world problem solving, with an emphasis on professional skills. Yet, an unanswered question remains: is student confidence in professional and technical engineering skills gained and retained when problem-based learning classes are only utilized in the freshman and senior-year year?

This research project longitudinally investigates the technical and professional skill development of mechanical engineering students at the University of Colorado at Boulder, where a *bookend* project-based curriculum is employed. The paper provides an overview of the First-Year Engineering Projects and the mechanical engineering Senior Capstone Design project course used for this study. Technical and professional skill objectives are also discussed within the paper. Pre and post skill surveys were used to assess First-Year Engineering Projects and the Senior Capstone Design classes. Results from two cohorts—followed longitudinally—indicate that student confidence in skills deteriorates between the end of the first-year and beginning of the senior year in five categories: *Engineering as a Career, Engineering Methods, Design, Communication and Teamwork*.

Motivation

At the University of Colorado at Boulder, all mechanical engineering (ME) undergraduates are required to take First-Year Engineering Projects (FYEP) and Senior Capstone Design (SCD) as part of their core curriculum. Both of these courses are project-centered, having a strong technical and professional component. The FYEP course is a single semester hands-on, team-based interdisciplinary design course for entry-level engineering students. Several faculty members from the College of Engineering and Applied Science teach the FYEP course. SCD is a yearlong industry sponsored, hands-on, design course for senior-level mechanical engineering students. The professional skills objectives for both courses include increasing: knowledge of engineering as a career, communication skills and teamwork skills. The technical skill learning objectives emphasize fundamental engineering methodologies and design skills.

Project-based courses are not currently incorporated into the sophomore or junior-level coursework at the University of Colorado at Boulder. Though a project may be supplementary to a course in the sophomore or junior year, the authors do not identify these courses as project-based since the learning is not organized around the project.

This research is an investigation of the growth of professional and technical skills in students throughout their undergraduate career, with a goal of targeting an appropriate curriculum structure to facilitate skill development. Given the ABET engineering accreditation criteria, and the industry expectations for entry-level engineers, it is imperative to understand and identify the most effective curricular organization for cultivating professional engineers.

The authors postulate that skill development of undergraduate engineers may be stunted when there is an absence of second and third-year project-based learning (PBL) opportunities. This research investigation addresses the following research questions:

- Are PBL courses enhancing engineering students' confidence in professional and technical skills?
- Are there changes in engineering students' confidence in their technical and professional skills between the end of the first year and beginning of the senior year?
- Are there changes in engineering student' confidence in their technical and professional skills between the beginning of the first year and the end of their senior year?

Previous studies have addressed the first research question[1-5] and the authors anticipated similar gains in student confidence during the University of Colorado at Boulder mechanical engineering PBL courses. This study deviates from previous PBL research by: 1) following two cohorts longitudinally through the engineering curriculum, 2) evaluating the effects of PBL within the context of a four-year bookend curriculum, specifically, investigating the phenomenon known locally as "the valley of despair" (sophomore and junior year) where no PBL courses are utilized.

Without the implementation of PBL courses in the sophomore or junior year of the mechanical engineering curriculum, the authors hypothesized that students' confidence in technical and professional skills would decline *significantly* between the end of the their first year and the beginning of the senior year. This hypothesis is represented by the Sawtooth model, seen in Figure 1. In this model, mean ratings only tell a portion of the PBL story. Statistically significant increases and decreases in student confidence over time are critical data from the Sawtooth model when understanding the retention of student skill confidence.

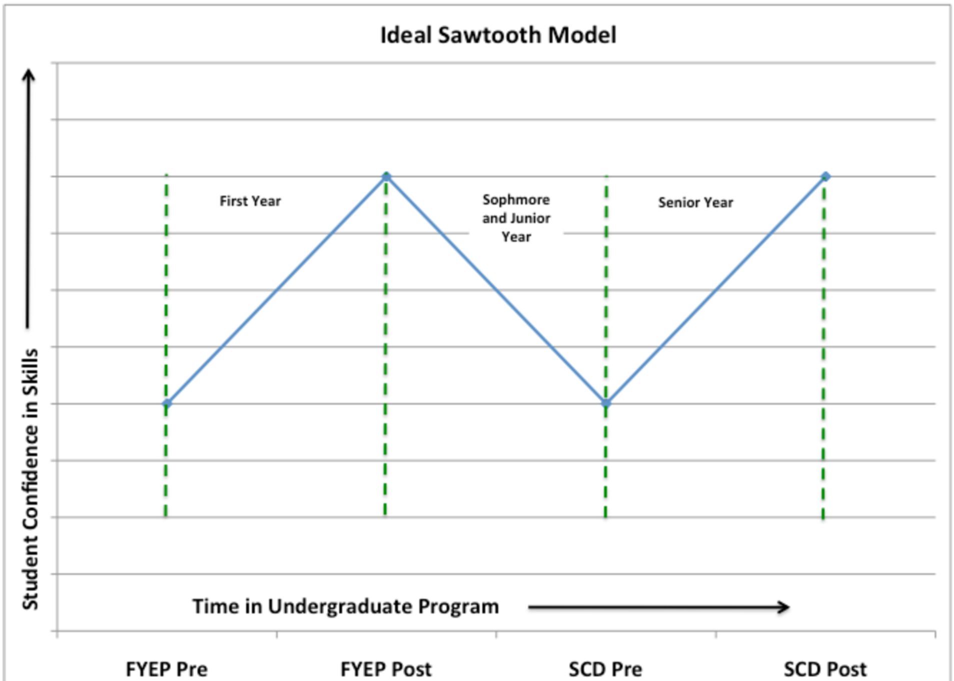

Figure 1: Proposed ideal sawtooth model for student confidence changes over time

Introduction

Theoretical Framework

The pedagogical approach underpinning this research is project-based learning. Due to the shorthand PBL, and the broad variety of practices classified as PBL, confusion can easily occur when reviewing literature on project and problem-based learning. Though there is significant overlap between the two approaches, there are also distinguishing characteristics for each technique.

Project and problem-based learning is inspired by the theories of Dewey,[6] Piaget[7] and Brunner,[8,9] as well as constructivist learning theory and situated learning theory.[10] Savery details the subtle differences in assigned tasks and instruction when comparing the two instructional approaches.[11] Savery effectively summarizes project-based learning as follows:

> *"Project-based learning is similar to problem-based learning in that the learning activities are organized around achieving a shared goal (project)….Within a project-based approach learners are usually provided with specifications for a desired end product (build a rocket, design a website, etc.) and the learning process is more oriented to following correct procedures…Teachers are more likely to be instructors and coaches (rather than tutors) who provide expert guidance, feedback and suggestions for "better" ways to achieve the final product."*[11]

Savage, et al. differentiates problem- and project-based learning in the context of engineering. In their discussion of the use of PBL to effectively develop skills for the global engineer Savage, et al. define:

> *"problem-based learning as pertaining to the development of knowledge based on the fundamental principles of science and mathematics and project-based learning to include mastering the engineering skills required to implement a design solution."*[12]

For the remainder of this paper, PBL will be used to represent project-based learning as defined by Savage, et al. The authors of this paper have also used five criteria, presented by Thomas[13] to identify and define project-based learning in this paper:

- PBL projects are central, not peripheral to the curriculum.
- PBL projects are focused on questions or problems that "drive" students to encounter (and struggle with) the central concepts and principles of a discipline.
- Projects involve students in a constructive investigation.
- Projects are student-driven.
- Projects are authentic.

Research in engineering education has demonstrated that project-based courses can increase student retention, motivation, problem-solving ability, communication skills, knowledge retention, teamwork skills and the capacity for self-directed learning.[1-5] Previous research has also shown that project-based FYEP and SCD classes increase the professional and technical design skills of students.[5,14] Several research studies indicate that a shortfall in professional training exists in the engineering classroom, as well as a lack of understanding about the true meaning and breadth of professionalism.[3] While research into first year and senior design skills development has been more robust, a scant amount of research investigating the transformation of skills between freshman design experiences and senior design experiences has been performed.[15]

Course Structure

The First-Year Engineering Projects course is offered as a hands-on introduction to engineering. Initiated in 1994, the three-credit, one-semester course now serves approximately 450 or 65% of incoming students per year in sections that cap at 32 students each. The course is required for mechanical, aerospace, civil, and environmental engineering majors, and is an elective for all other engineering students. The main goal of the course is an integrative one—to make connections between the theoretical, academic aspects of engineering and the professional practice of engineering, helping budding engineers understand that engineering is a helping, people oriented profession that underpins both our economy and our quality of life. This is accomplished through introducing students to the design/build process in a team-based setting, supported by experimental testing. Course components include team dynamics and communications/social styles workshops and a comprehensive design project in which students experience the complete design-build-test cycle of product prototype development. Many projects are developed for clients—introducing the ambiguity of evolving customer demands into product design specifications. The design/build cycle culminates in an end-of-semester design expo at which prototypes are showcased to the public.

The Senior Capstone Design course is a yearlong industry sponsored design experience. Approximately 150 mechanical engineering students take this required course each year. The course strives to form five person teams who work closely with sponsoring companies to determine final project scope, develop design alternatives, manufacture, assemble and test desired products. Student teams are advised by a ME faculty member and Industry Mentors representing the sponsoring company or corporation. Several of the SCD faculty advisors are professional engineers serving as adjunct faculty. Course components include project management, team dynamics, CAD and writing workshops. An end-of-year senior design expo allows students to display final deliverables for industry judges, as well as the public.

The skills objectives for both courses emphasize design skills, communication skills, teamwork skills and engineering methods. Additional professional skills and project management are also part of the learning objectives for the SCD course.

The FYEP and SCD courses exemplify only two possible PBL course models. It should be noted that there are several different pedagogical models for structuring PBL curriculum. This includes the continuous integration of PBL in sophomore, junior year classes,[15] as well as service learning opportunities.

Methods

A paired sample of 90 mechanical engineering students was used to evaluate the longitudinal impact of a mechanical engineering curriculum with only first year and senior year PBL experiences. The assessment tools utilized for data collection in this project included:

- Pre and post-year FYEP and SCD course surveys targeting students' self-confidence in skill development and aligning with the goals of the courses. The surveyed categories included:
    - *Engineering as a Career* — knowledge of the different types of engineering careers and societal impacts of engineering.
    - *Engineering Methods* — engineering related software skills and manufacturing skills.
    - *Design Skills* — implementation of the design loop and designing within context.
    - *Communication Skills* — oral and written technical communication.
    - *Teamwork Skills* — conflict resolution, group cohesion and work quality.

Course pre- and post- surveys were administered in First Year Engineering Projects across three years (fall 2003 to spring 2006). Three years of FYEP data was used to account for students who take five years to complete the undergraduate curriculum. The SCD pre-course survey was taken in the fall of 2007 and 2008. Students completed the SCD post-course survey in the spring of 2008 and 2009. The 90 students represent two distinct cohorts, the senior mechanical engineering class of 2008 and 2009.

Results

The data were analyzed with a repeated measures analysis of variance procedure to determine if significant differences exist between assessment times. Data analysis results were significant (F, 14.91; $p < .05$) indicating that the proposed Sawtooth model is valid across all of the surveyed categories (Knowledge of Engineering as a Career, Engineering Methods, Engineering Design, Communication and Teamwork skills). For each category student confidence increased significantly during the FYEP course, deteriorated significantly during the sophomore and junior year, then subsequently increased significantly during the SCD course. Student rated mean confidence is used for the y-axis in Figure 2 – Figure 6, with 1.00=not confident, 3.00=neutral and 5.00=highly confident. P-values for each category can be found along the slopes of Figure 2 – Figure 6.

Student rated confidence in their Knowledge of Engineering as a Career (Figure 2) started with a mean of 3.64 and increased significantly to a mean of 4.12 during the First-Year Engineering Projects course. Between the Post FYEP survey and the Pre SCD survey (the sophomore and junior year), student confidence in their Knowledge of Engineering as a Career decreases significantly to a mean of 3.78. Student confidence increased significantly to a mean of 4.06 by the end of the Senior Capstone Design course. There is no statistical difference between the Pre FYEP survey and Pre SCD means, suggesting that the level of confidence in knowledge of the different types of engineering careers and the societal impacts of engineering is equal at the beginning of the first year and the beginning of the senior year. Additionally, there is no statistical difference in the post survey means.

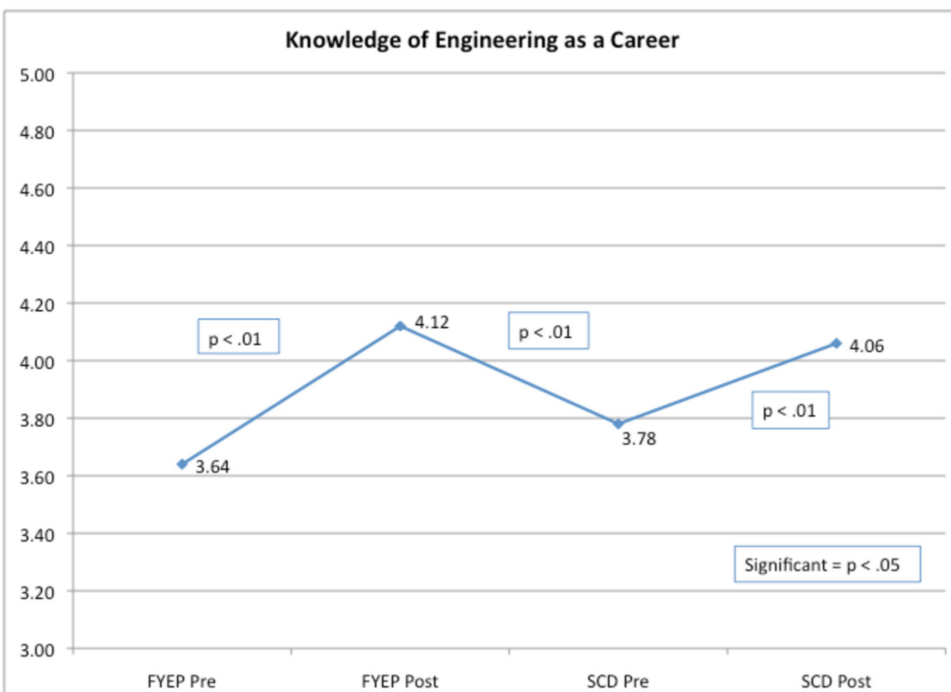

Figure 2: Mean ratings for Knowledge of Engineering as a Career

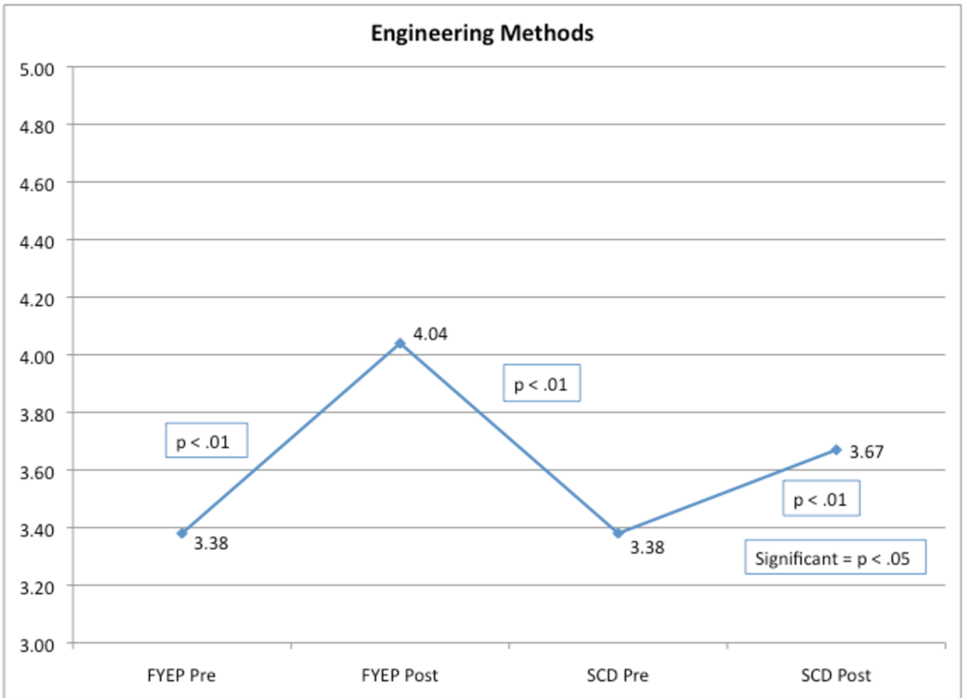

Figure 3: Mean ratings for Engineering Methods

Student confidence in Engineering Methods followed the same pattern as Knowledge of Engineering as a Career (see Figure 3). The initial self-rated mean was 3.38 increasing significantly to a mean of 4.04 at the Post FYEP. Confidence deteriorated significantly to 3.38 at the start of Senior Capstone Design and increased to a final mean of 3.67 by the end of the SCD course. Deterioration in confidence was more severe for Engineering Methods than the previous category. It should be noted that student confidence in their Engineering Methods skills was rated statistically equivalent during the start of First-Year Engineering Projects and the beginning of their senior year. Furthermore, the Post FYEP mean remained statistically higher than the Post SCD mean ($p<0.1$), indicating that students never achieved the same confidence in their engineering related software skills and manufacturing skills in their senior year as they did their first year of college.

Similar trending occurs in the Design, Communication, and Teamwork skill categories (Figure 4 – Figure 6). As seen in Knowledge of Engineering as a Career and Engineering Methods, the proposed sawtooth model is apparent—student confidence increasing significantly during the FYEP course, deteriorating significantly during the sophomore and junior year, then increasing significantly during the SCD course.

When assessing Design skills, students experienced a significant increase in confidence during their First-Year Engineering Projects course (Pre FYEP mean = 3.25 and Post FYEP mean = 3.89, Figure 4). Confidence in these skills decreased significantly during the sophomore and junior year to a Pre SCD mean = 3.50. By the conclusion of the Senior Capstone Design, student confidence increased to a Post SCD mean = 4.10. As discussed in the *Methods* section, these means represent an assessment of student confidence in their ability to implement the design

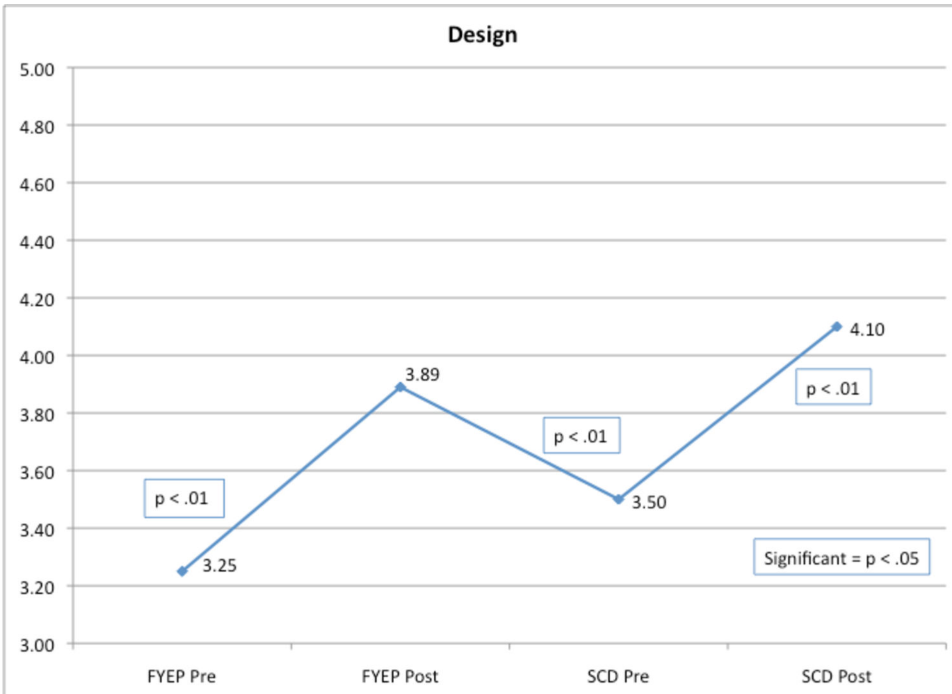

Figure 4: Mean ratings for Design

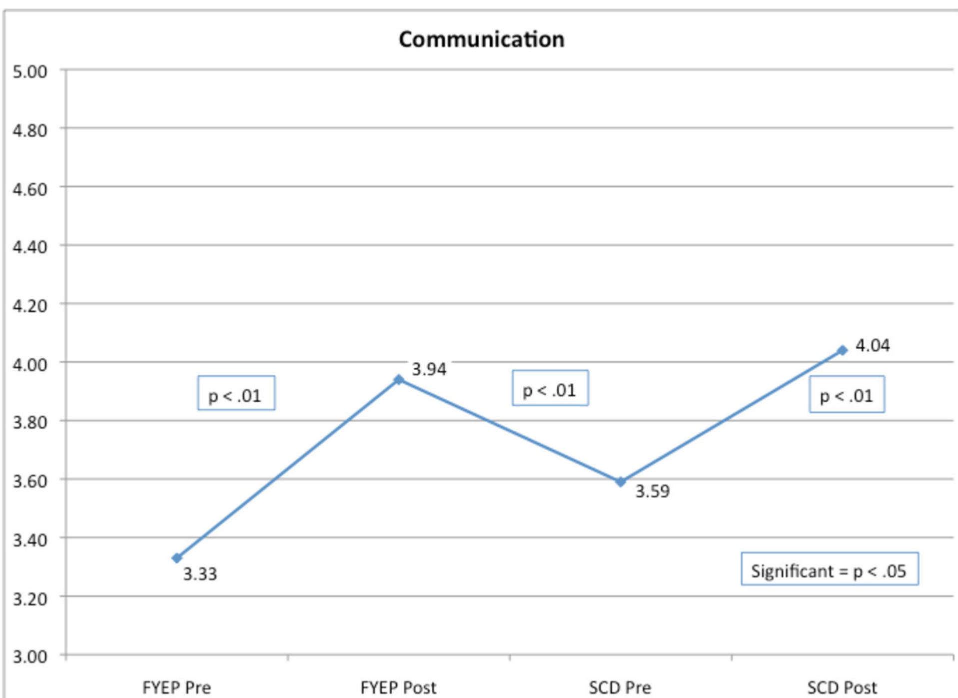

Figure 5: Mean ratings for Communication

loop and design within context. Students did experience significant gains ($p<0.01$) in confidence between the Pre FYEP and Pre SCD survey administration. Additionally, there were significant gains ($p<0.01$) in confidence between the Post FYEP and Post SCD survey for the Design Skills category. This indicates that student's highest level of confidence in their Design Skills occurred at the end of the Senior Capstone Design course.

Confidence ratings for communication started with a mean of 3.33 at the Pre FYEP and increased significantly to 3.94 at the end of the First Year Projects course (Figure 5). Student confidence dropped significantly to 3.59 at the Pre SCD survey, followed by a significant increase at the end of the year (Post SCD mean = 4.04). A significant gain ($p<0.01$) can be found between the Pre FYEP and the Pre SCD survey. This provides evidence that students are more confident in their oral and written technical communication at the beginning of their senior year, compared to the beginning of the First Year Projects course.

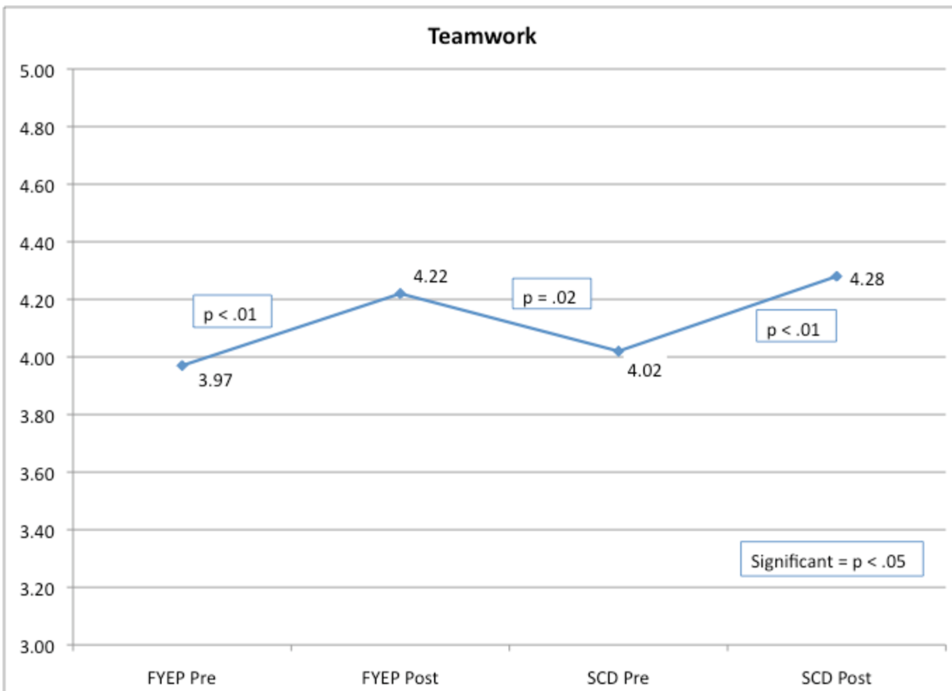

Figure 6: Mean ratings for Teamwork

For teamwork skills (Figure 6), student confidence started at 3.97 and rose significantly to 4.22 at the end of their FYEP experience. There was a significant decline in mechanical engineering student's teamwork skills by the beginning of the senior year to 4.02. However, by the end of the SCD course confidence in teamwork skills had made a significant gain to 4.28. Statistically, there was no difference between the Pre FYEP and SCD means, or the Post FYEP and SCD means. Looking at Figure 6, one can see that the sawtooth model shape is evident. However, student confidence in their Teamwork skills starts relatively high and remains at that level—resulting in a flat graphical representation with moderately changes in confidence.

For all five categories, there is a statistical increase in student confidence means when comparing the Pre FYEP and Post SCD. This suggests that student confidence in these skill areas does increase between the time they enter the mechanical engineering program and graduation from the program.

Discussion and Conclusions

This study uncovered statistical evidence that confidence in skill development of undergraduate mechanical engineers declines in the absence of project-based learning courses. The three fundamental research questions identified in the *Motivation* section of this paper are addressed in the following paragraphs.

Research question 1: Are PBL courses enhancing engineering students' confidence in professional and technical skills?

There is evidence that the First-Year Engineering Projects and Senior Capstone Design courses are increasing student confidence in technical and professional skills. The upward trend in each sawtooth of the five categories is statistically significant. This indicates that PBL courses are enhancing the professional and technical skills of engineering skills. This reported gain in student confidence was expected by the authors and aligns with the findings of Savage et al.[3] and Hendy, P.L. and Hadgraft.[16]

Research question 2: Are there changes in engineering students' confidence in their technical and professional skills between the end of the first year and beginning of the senior year?

Yes, there is deterioration in student confidence in both professional and technical skills between the end of the first year and the beginning of the senior year. A negative slope is apparent in figures 2-6, and the decline is statistically significant for all the assessed categories as follows:

- *Engineering as a Career* — knowledge of the different types of engineering careers and societal impacts of engineering.
- *Engineering Methods* — engineering related software skills and manufacturing skills.
- *Design Skills* — implementation of the design loop and designing within context.
- *Communication Skills* — oral and written technical communication.
- *Teamwork Skills* — conflict resolution, group cohesion and work quality.

During the absence of PBL courses, year two and three of the mechanical engineering curriculum, confidence in these crucial engineering skills decline. This begs the question: are the student skill benefits associated with PBL short term? Meaning if students do not practice the professional and technical skills listed above—do they loose the proficiency to perform these skills? The "problem set" pedagogy that still dominates the middle two years of the engineering curriculum does not provide students with the opportunity to apply their professional and technical skills in an authentic manner. Rather, the typical textbook assignment provides students with all of the information on a single page, and the ability to solve using a single textbook with a preordained answer. These problems lack the context, complexity, and ambiguity, evident in PBL courses, that today's engineers must cope with as 21^{st} century global engineers.

Research question 3: Are there changes in engineering student' confidence in their technical and professional skills between the beginning of the first year and the end of their senior year?

Yes, students are leaving mechanical engineering with increased confidence in their technical and professional skills. However, there is room for improvement, particularly in the area of Engineering Methods where the mean was a 3.67 on the post SCD Engineering Methods skill assessment. Our goal is to move scale means above 4.0 indicating an average student rating of "confident."

It is reasonable to question: if students started at a higher confidence level at the beginning of their senior year, would there be similar gains in confidence—resulting in a higher end confidence rating? The question also remains, would we see a more linear trend instead of a sawtooth form, with the inclusion of PBL courses in the sophomore and junior year? It would be advantageous to investigate if four-year PBL course exposure would lessen the decline between the end of the first year and beginning of the senior year (i.e., eliminate any significant decline in confidence).

Project Limitations

The authors recognize that there is controversy regarding the relationship between student self-rated confidence in skills and skill evaluation by an objective source. One solution to this limitation is to triangulate the data with faculty and industry assessment of students in the Senior Capstone Design course. Future research will compare the rating of SCD students with the rating of industry and faculty advisors.

Future Work/Recommendations

It is the belief of the authors that integrating complex and rich design experiences throughout the curriculum will continuously build and maintain technical and professional skills. Specifically, the authors recommend that at least one PBL course be required on a yearly basis. The authors posit that the inclusion of a problem-based learning course at each grade level will eliminate the statistical decline in engineering skills that is salient in a bookend curriculum. Though this recommendation has been made in other studies,[3, 17] little research has been completed to systematically investigate the inclusion of PBL courses in the sophomore and junior year and evaluate the outcomes quantitatively and qualitatively.

The brings us to the next step in this research plan which is to triangulate student confidence self-ratings with external evaluators (faculty advisors and industry mentors) Senior Capstone Design. Additionally, a junior course will be reformed as a PBL course (meeting the five criteria for inclusion as a PBL course presented in the *Theoretical Framework*) and offered in Spring 2010. Future work will evaluate student skill development in a three year PBL curriculum and compare these data to the current mechanical engineering bookend curriculum.

Acknowledgements

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